Vegetable health and crop protection

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Insecticides and agricultural pest control: the magnitude of its use in crops in some provinces of Ecuador

Los insecticidas y el control de plagas agrícolas: la magnitud de su uso en cultivos de algunas provincias de Ecuador

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Abstract

In agricultural pest control, insecticides represent the main available alternative. To analyze the magnitude of its use, 539 interviews to farmers were carried out considering the following crops: Cucurbitaceae: melon, *Cucumis melo*, and watermelon, *Citrullus lanatus*; Fabaceae: common bean, *Phaseolus vulgaris*; Solanaceae: potato, *Solanum tuberosum*, pepper, *Capsicum annuum* and tomato, *Solanum lycopersicum*, located in the provinces of Chimborazo, El Oro, Guayas, Loja and Santa Elena. Information was requested on important pests and type of management; if chemical pesticides were used, the following information was registered: Generic name, the active ingredient, acute toxicity, dosage, spraying frequency, waiting periods, and product mixture. All interviewed farmers expressed the use of insecticide mixtures, raising the recommended dosages without considering the waiting periods of each product. Additionally, farmers reported 2.6, 1.1, 0.5, 2.0, and 2.8 weekly aspersions for cucurbits (melon and watermelon), common bean, potato, pepper, and tomato, respectively. The main pests mentioned were: aphids (Hemiptera: Aphididae) in cucurbits and pepper, *Liriomyza* spp. (Diptera: Agromyzidae) in common bean, *Premnotrypes vorax* (Coleoptera: Curculionidae) in potato and *Prodiplosis longifila* (Diptera: Cecidomyiidae) in tomato. Approximately 80 % of the insecticides used belong to Class I and II. The results indicated high spraying frequencies, high dosages and high toxicity for vertebrates with the insecticides used by farmers. Given the impact of insecticides, it is necessary to study imbalances in agroecosystems, effects on health, and also on the environment, as well as to validate more rational ecological and socio-economic alternatives.

Keywords: crop management, ecological imbalances, environmental impact, pesticides, sustainability

Resumen

En el control de plagas agrícolas, los insecticidas representan la principal alternativa disponible. Para analizar la magnitud de su uso, se realizaron 539 entrevistas a agricultores en los siguientes cultivos: Cucurbitaceae: melón, *Cucumis melo*, y sandía, *Citrullus lanatus*; Fabaceae: frijol, *Phaseolus vulgaris*; Solanaceae: papa, *Solanum tuberosum*, pimiento, *Capsicum annuum*, y tomate, *Solanum lycopersicum*, ubicados en las provincias Chimborazo, El Oro, Guayas, Loja y Santa Elena, en Ecuador. Se recabó información sobre plagas importantes, tipo de manejo y si resultaba plaguicida químico, y se consignaba nombre genérico, ingrediente activo, toxicidad aguda, dosificación aplicada, frecuencia de aspersiones, periodos de carencia y mezclas de productos. El total de los entrevistados manifestó utilizar mezclas de insecticidas, generalmente elevando las dosificaciones recomendadas sin tomar en cuenta los periodos de carencia. Además, señalaron realizar 2,6, 1,1, 0,5, 2,0 y 2,8 aspersiones semanales en promedio para cucurbitáceas (melón y sandía), frijol, papa, pimiento y tomate, respectivamente. Las plagas principales mencionadas fueron áfidos (Hemiptera: Aphididae) en cucurbitáceas y pimiento; *Liriomyza* spp. en frijol (Diptera: Agromyzidae), *Premnotrypes vorax* (Coleoptera: Curculionidae) en papa y *Prodiplosis longifila* (Diptera: Cecidomyiidae) en tomate. Aproximadamente el 80 % de los insecticidas utilizados pertenecen a las Clase I y II. Los resultados indicaron altas frecuencias de aspersiones, dosificaciones elevadas y alta toxicidad para vertebrados en los insecticidas usados. Dado el impacto de los insecticidas, es necesario estudiar los desequilibrios en los agroecosistemas, efectos en la salud y el ambiente, así como validar alternativas ecológicas y socioeconómicamente más racionales.

Palabras clave: desbalances ecológicos, impacto ambiental, manejo del cultivo, plaguicidas, sostenibilidad

Introduction

From the second half of the twentieth century, the agricultural production extension process in Ecuador has been accompanied by the use of modern technologies based on the high use of chemical inputs, among which insecticides stand out (Crissman, Espinoza, & Herrera, 2002; Naranjo, 2017). However, the use of these chemical technologies is generally not supported by sufficient research about the impact of the frequent use of insecticides on the structure and functioning of agroecosystems. Therefore, the indiscriminate use of chemical pesticides, instead of reducing pest problems, often increases them, leading to serious production problems, either due to ecological imbalances or to the emergence of insect and mite resistance to these products (Chirinos & Geraud-Pouey, 2011; Chirinos, Diaz, & Geraud-Pouey, 2014; Nicholls, 2008).

Despite excessive applications of chemicals for pest control, on several occasions, devastating attacks by some insects that farmers could not control, have occurred (Chirinos & Geraud-Pouey, 2011). The high cost within the production economy, together with huge losses due to out-of-control pests, has represented severe limitations for crop production (Herrera, 2010; Nicholls, 2008; Pimentel, 2005). Besides, continuous applications of toxic products pose severe health risks for agricultural operators and consumers (Del Puerto, Suárez, & Palacio, 2014; Fernández, Mancipe, & Fernández, 2010; Naranjo, 2017; Pimentel, 2005). Furthermore, the soil and water pollution problems that these cause, re critical (Aktar, Sengupta, & Chowdhury, 2009; Castillo, Subovsky, Sosa, & Nunes, 2007; Flores-García, Molina-Morales, Balza-Quintero, Benítez-Díaz, & Miranda-Contreras, 2011; Molina-Morales, Flores-García, Balza-Quintero, Benítez-Díaz & Miranda-Contreras, 2012).

These aspects make it necessary to reconsider the approaches to agricultural production, especially concerning fundamental ecological and socio-economic criteria related to benefits and losses and retake, for example, ancestral forms of pest management, making them evolve within the framework of new scientific and technological knowledge.

As a first step to redirect the pest management criteria, it is necessary to document the chemical insecticide use magnitude, to generate pest management programs aimed at reducing the use of these agrochemicals with high environmental impact. In this sense, this work aimed at analyzing the insecticide use magnitude in the management of pests in economically important crops in some localities of Ecuador.

Materials and methods

During the period from March 2015 to April 2016, 539 interviews were conducted in Ecuador, with a total of 578 farmers distributed in 13 locations, including the provinces of Chimborazo, El Oro, Guayas, Loja and Santa Elena (table 1, figure 1). The crops were selected according to the list of most important crops in the study area (Instituto Nacional de Estadística y Censos [INEC 2017), as follows: Cucurbitaceae: melon, *Cucumis melo* L., watermelon, *Citrullus lanatus* (Thunb.); Fabaceae: common bean, *Phaseolus vulgaris* L.; Solanaceae: potato, *Solanum tuberosum* L., pepper, *Capsicum annuum* L., and tomato, *Solanum lycopersicum* L. These crops are cultivated in open fields and are normally used for domestic consumption.

In the province of Chimborazo, surveys were conducted to common bean, pepper, and tomato producers in the Pallatanga canton; and in the Colta canton, potato producers were interviewed. In the province of El Oro, surveys were applied in the lower altitude areas of Arenillas, Chacras, and Palmales to melon, watermelon, pepper, and tomato producers, meanwhile in high altitude areas as in Chillas, potato producers were surveyed. In the case of the province of Guayas, the surveys were applied in Pedro Carbo, Sabanilla, and Milagro to melon, watermelon, tomato, and pepper producers. In the province of Loja, potato producers from Malacatos and Vilcabamba were interviewed. Finally, in the province of Santa Elena, melon, watermelon, and tomato producers from the Chanduy and El Morro areas were surveyed. Based on the total number of

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farmers per region throughout provinces, the sample size for the interviews was calculated, applying equation 1 for finite populations.

$$n = \frac{N.Z\alpha^2.p.q}{d^2.(N\text{-}1) + N.Z\alpha^2.p.q} \qquad \text{Equation 1}$$

Where N is the total population, $Z\alpha$ is 1.96 squared (with 95% certainty = 0.95), p is the expected proportion (in this case, 5% = 0.05), $q = 1 - p$ (in this case 1 - 0.05 = 0.95), and d is the precision (5% = 0.05).

The number of farmers interviewed per crop obtained from the calculation of the sample size are indicated in table 2. The requirements of the surveys are shown in figure 2. With the information on the names of the pest species treated per crop, each producer was asked to mention the three most relevant pest problems in order, from 1 to 3, with 1 being the most important. With this ranking exercise, the percentage of importance referred to by the producer for each pest and the percentage of farmers who use insecticides as their primary management alternative, the products most used per crop, the use frequency (expressed as a percentage of applications with respect to the total number of insecticides applied and separated by toxicity categories), were calculated (World Health Organization [WHO], 2009). Besides, the average weekly insecticide sprayings for each crop and the active ingredient (ai) dosage per liter of mixture were established.

Table 1. Total number of farmers per province and crop assessed

Province	Crops					
	Melon	**Watermelon**	**Common bean**	**Potato**	**Tomato**	**Pepper**
Chimborazo	0	0	50	20	35	25
El Oro	15	15	0	12	17	22
Guayas	60	60	45	0	32	25
Loja	0	0	0	30	0	0
Santa Elena	40	35	0	0	15	25
Total	115	110	95	62	99	97

Source: Elaborated based on the data from of INEC (2017) per province (including localities)

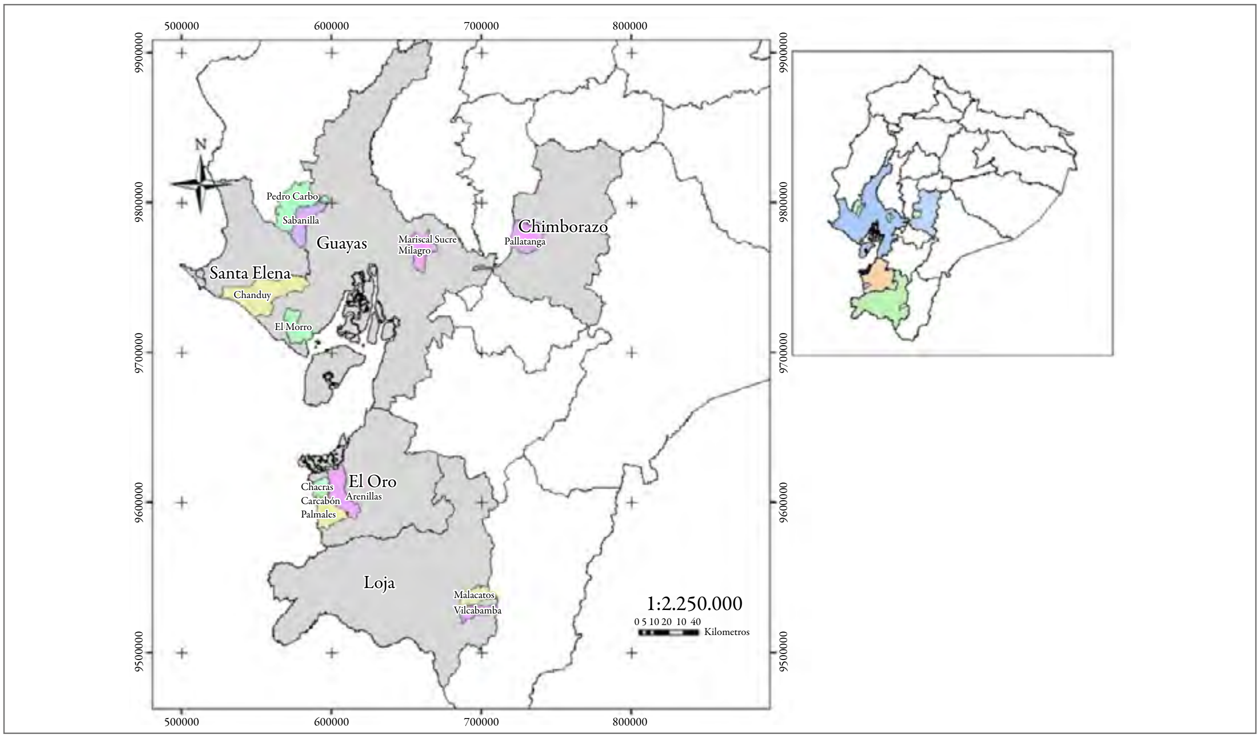

Figure 1. Map of Ecuador showing the study locations in the provinces visited. This figure was elaborated with the ArcGIS 10.1 program.
Source: Elaborated by the authors

Table 2. Number of farmers interviewed by province and crop, calculated with the sample size calculation equation for finite populations based on the total number of farmers in the study area

Province	Crops					
	Melon	Watermelon	Common bean	Potato	Tomato	Pepper
Chimborazo	0	0	45	20	33	23
El Oro	15	15	0	12	17	21
Guayas	53	53	41	0	30	24
Loja	0	0	0	28	0	0
Santa Elena	37	33	0	0	15	24
Total	105	101	86	60	95	92

In cells with zero (0) interviews, the crop is not prevalent in the locations visited.
Source: Elaborated by the authors

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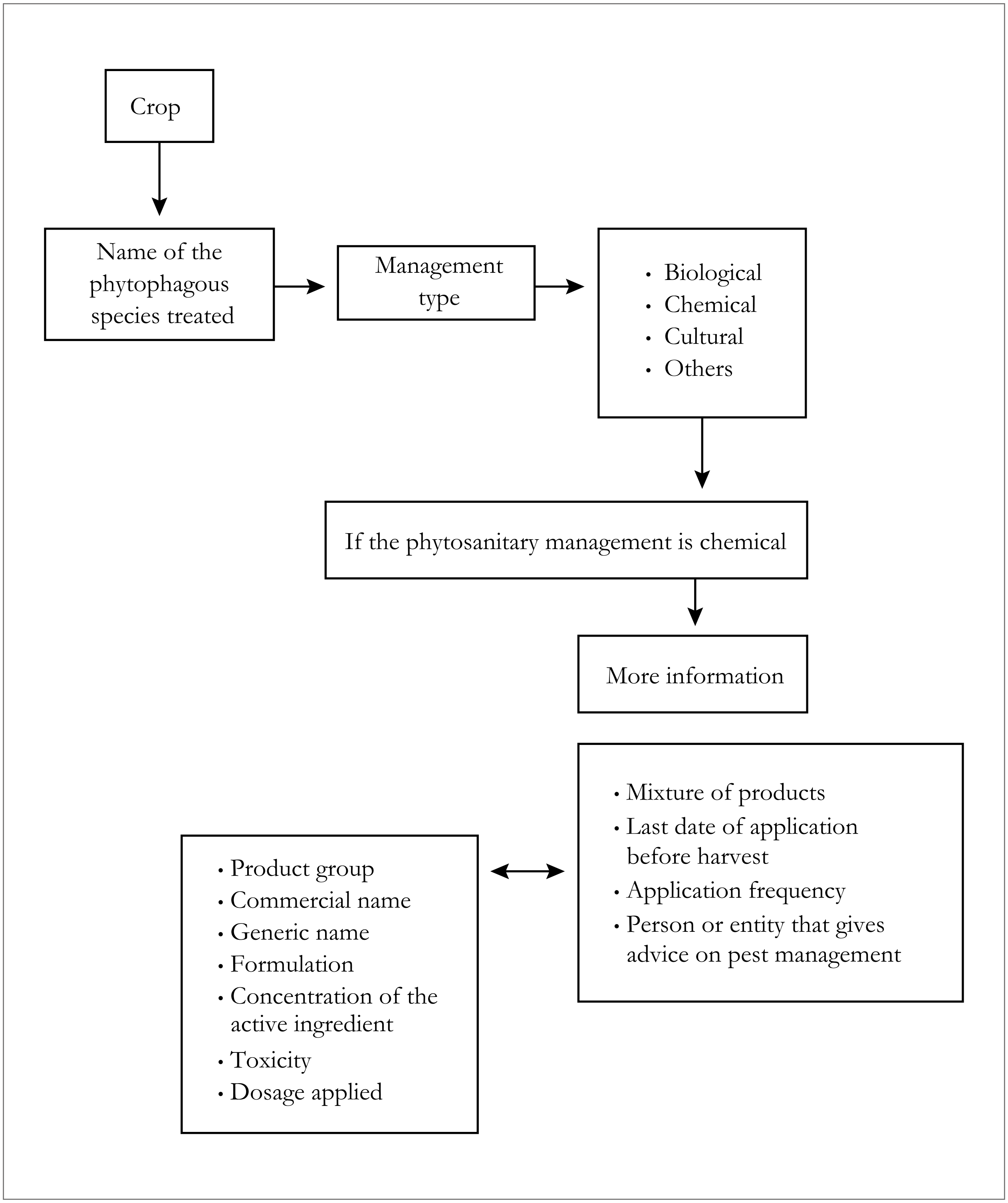

Figure 2. Information contained in the surveys applied to farmers by crop in the study areas.
Source: Elaborated by the authors

During the visits, samples of adult individuals of important insects associated with the crops prevalent in the area were collected, to corroborate the identification made by the farmers. To identify adult individuals of parasitoids associated with *Liriomyza* species (in larval phase and puparium), these were placed for breeding (at a temperature between 25-26 °C and relative humidity between 66-72 %), in the Entomology Laboratory of Universidad Agraria del Ecuador. The methodology followed for breeding has been referred to by Chirinos, Castro, and Garces (2017). Leaves collected in the field with damage made by *Liriomyza* spp. were placed in rectangular plastic trays (20 cm × 28 cm × 6 cm; width × length × height) containing moistened absorbent paper to extract larvae and pupae from parasitoids developed from parasitized *L. sativae* larvae. Once the pupae of the parasitoids were formed, these were placed individually in transparent gelatin capsules until the adults emerged. On the other hand, the puparium from miners was also obtained from the tray and transferred to plastic Petri capsules (9 cm in diameter) that contained moistened absorbent paper inside. From the puparium, the emergence of the adult of the phytophagous insect or any parasitoid was expected.

The collected adults were identified by comparison with existing reference specimens at the Arthropod Museum of Universidad del Zulia, Maracaibo, Zulia state, Venezuela, and are maintained in the entomological collection of Universidad Agraria del Ecuador, in Guayaquil, Ecuador.

During the surveys, the insecticides mentioned coincided by crop, regardless of the province visited, so the situation of insecticide applications was analyzed for each crop separately, except in the case of Cucurbitaceae, where there are many similarities in cycle, pest species, and controls; therefore, the crops (melon and watermelon) are treated in the results as Cucurbitaceae.

Statistical analysis

Descriptive statistics (means) were employed for the different variables assessed. Pesticides were evaluated for toxicity using the Chi-Square test ($p < 0.05$). The problems, in order of importance, were analyzed using the Kruskal-Wallis H test ($p < 0.05$). The dosages used and recommended were compared using the Wilcoxon test ($p < 0.05$).

Results and discussion

All the interviewees indicated that they base their insect pest control on the application of chemical insecticides, whose results are analyzed below by crop.

Cucurbitaceae

The major pest problems farmers mentioned were the aphid *Aphis gossypii* Glover (Hemiptera: Aphididae) and whiteflies of the *Bemisia tabaci* (Gennadius) complex, followed by larvae of the genus *Diaphania* (Lepidoptera: Crambidae), the melon-worm moth *Diaphania hyalinata* L., and the pickle-worm *Diaphania nitidalis* Stoll (table 3; $p < 0.05$). Producers control these pests spraying insecticides at an average of 2.6 times weekly (range: 2-3; table 3). These spraying frequencies are much higher than those reported by Valarezo, Cañarte, Navarrete, Guerrero and Arias (2008), who indicated that 100 % of melon and watermelon producers in the province of Santa Elena, Ecuador, applied insecticides approximately once a week to control whiteflies, which they describe as an "extremely high use of insecticides".

Farmers indicated that to handle sucking insects, they mainly used neonicotinoid insecticides, which agrees with what has been reported by Valarezo et al. (2008). *Diaphania* species were controlled with methomyl, methamidophos, profenofos, and fipronil; the first three are very toxic and have the highest use percentage (table 4) compared to the last (table 5). The weekly frequency applications obtained in this study represent 23 to 34 in total throughout one crop cycle that lasts from 60 to 90 days. Vargas-González et al. (2016) indicated 21 pesticide applications during a melon cultivation cycle in Comarca Lagunera, Mexico, which is lower compared to what has been estimated here.

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Table 3. Number of weekly sprays (Ap) (mean ± standard deviation) and main pest problems identified in different crops

Crop	Ap	N	Main problems (% of referred importance)
Cucurbitaceae (melon + watermelon)	2,6 ± 0,8	206	1. *Aphis gossypii* (34,95 % a) 2. *Bemisia tabaci* (33,02 % a) 3. *Diaphania hyalinata* and *D. nitidalis* (32,03 % b)
Common bean	1,1 ± 0,4	86	1. *Liriomyza* spp. (40,70 % a) 2. *Aphis craccivora* (36,04 % ab) 3. Moscas blancas (23,26 % b)
Potato	0,5 ± 0,3	60	1. *Premnotrypes vorax* (55,00 % a) 2. *Epitrix* sp. (26,67 % b) 3. Polillas minadoras (Gelechiidae) (18,33 % c)
Pepper	2,0 ± 0,7	92	1. Áfidos *A. gossypii*, *Myzus persicae* (37,89 % a) 2. *Polyphagotarsonemus latus*, *Tetranychus urticae* (35,78 % a) 3. *Prodiplosis longifila* (26,33 % b)
Tomato	2,8 ± 0,8	95	1. *P. longifila* (73,91 % a) 2. *Liriomyza* spp. (Diptera: Agromyzidae) (16,30 % b) 3. Moscas blancas (Hemiptera: Aleyrodidae) (9,79 % b)

% of referred importance. Means with the same letter do not differ significantly. Comparisons made with the Kruskal-Wallis H Test ($p < 0.05$)
Source: Elaborated by the authors

Fabaceae: *Phaseolus vulgaris*: common bean

The pests referred to by farmers for bean cultivation were the leaf miners *Liriomyza sativae* and *Liriomyza huidobrensis* (Blanchard) (Diptera: Agromyzidae), as well as the black aphid *Aphis craccivora* Koch (Hemiptera: Aphididae), followed by the whitefly species *B. tabaci* and *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae) (table 3; $p < 0.05$). The leaf miners and the whiteflies species are considerably polyphagous (Tong-Xian, Kang, Heinz, & Trumble, 2009; Abdul-Rassoul & Al-Saffar, 2014; Chirinos et al., 2014; Romay, Geraud-Pouey, Chirinos & Demey, 2016); however, independently of the host plants, during this study, differences regarding their altitudinal distribution were found. Thus, *L. sativae* and *B. tabaci* were found in low areas of El Oro and Guayas; meanwhile *L. huidobrensis* and *T. vaporariorum*, were found in high areas of Chimborazo, Loja, and El Oro. For the control of leaf miners, farmers mainly use abamectin and cypermethrin plus lambda-cyhalothrin (table 5); however, they also use organophosphates (methamidophos) and carbamates (methomyl) (table 4), performing on average, a weekly application, generally mixing some of the insecticides mentioned above. In the case of the black aphid and whiteflies, farmers indicated applying acetamiprid and buprofezin, respectively (table 7).

The way in which farmers reported using insecticides in common beans, especially to control leaf miners, is controversial, given the presence of natural biological controllers. Among these, we found some parasitoid species, such as *Closterocerus* sp. and *Chrysocharis* sp. (Hymenoptera: Eulophidae) (larval parasitoids), as well as *Ganaspidium* sp. (Hymenoptera: Figitidae) and *Halticoptera* sp. (Hymenoptera: Pteromalidae) (parasitoids larva-puparium). This diversity of parasitoids associated with *Liriomyza* is frequently mentioned in the literature (Abdul-Rassouly & Al-Saffar, 2014; Hernández, Guo, Harris, & Liu 2011; Osmankhil, Mochizuki, Hamasaki, & Iwabuchi, 2010).

Table 4. Extremely dangerous (Ia) and very dangerous (Ib) toxic insecticides (Class I) with the dosage (g or mL of active ingredient/L) used (DU) and recommended (RD), and the use percentage in major crops in the provinces of Ecuador assessed

Crop	Insecticide	Chemical Group	DU	RD	Use %
Potato, pepper	Carbofuran	Carbamate	0,7 - 1,75	0,6	5,0
Cucurbits, common bean, potato, pepper, tomato	Methamidophos	Organophosphate	1,2 - 1,8	0,8	11,3
Cucurbits, common bean, pepper, tomato	Methyle	Carbamate	0,4 - 1,1	0,5	7,1
Cucurbits, common bean, potato, pepper	Profenofos	Organophosphate	0,75 - 2,5	0,8	12,1

Source: Elaborated by the authors

Field experiments conducted by Chirinos et al. (2017) with the leaf miner *L. sativae* in Ecuador, showed that in common bean plots free of insecticide applications, there was high parasitism associated with low populations of this phytophagous. This contrasts with what was observed in other plots treated with continuous applications of chemical insecticides, where high levels of pest populations were associated with a low percentage of parasitism. These results, together with research conducted in other latitudes (Chirinos et al., 2014; Tran, 2009; Tran, Tran, Konishi, & Takagi, 2006), suggest that insecticide applications for insect control are unnecessary and interfere with the natural biological control of these species, which can generate resistance risks.

Solanaceae: *Solanum tuberosum*: potato

Farmers mentioned the Andean potato weevil *Premnotrypes vorax* Hustache (Coleoptera: Curculionidae) as the most relevant problem for potato cultivation. The flea beetles *Epitrix* sp. (Coleoptera: Chrysomelidae) and several species of mining moths (Lepidoptera: Gelechiidae) were referred to in second and third order of importance ($p < 0.05$), respectively. For the control of these insects, farmers carried out the application of insecticides every 15 days, which is similar to what has been found in other areas of the country (Aldás, 2012). *Premnotrypes vorax* is considered an essential problem for this crop (Gallegos, Avalos, & Castillo, 1997). To control it, despite some legal restrictions (Agencia de Regulación y Control Fito y Zoosanitario [Agrocalidad], 2013), farmers used carbofuran. Furthermore, the use of insecticides containing mixtures of lambda-cyhalothrin and thiamethoxam, as well as others used individually (lambda-cyhalothrin, cypermethrin, methamidophos or profenofos) was also highlighted. These results are similar to those obtained by Aldás (2012), who observed that the insecticides mostly used in the control of potato pests were mixtures of commercial formulations of lambda-cyhalothrin and thiamethoxam, or carbofuran and lambda-cyhalothrin.

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Table 5. Moderately hazardous insecticides (Class II) and dosage (g or mL of active ingredient/L) used (DU) and recommended (RD) in some crops in the southwestern provinces of Ecuador assessed

Crops	Insecticide	Chemical Group	DU	DR	Use %
Cucurbits, common bean, pepper, tomato	Abamectin	Avermectin	0,02-0,04	0,02	2,1
Common bean, potato, tomato	Cypermethrin	Pyrethroid	0,5-1,25	0,2	5,0
Tomato	Chlorpyrifos	Organophosphate	1,9-2,9	0,5	1,4
Pepper, tomato	Diazinon	Organophosphate	0,9-1,8	0,6	1,4
Common bean, pepper	Dimethoate	Organophosphate	0.8-1,6	0,4	0,7
Pepper, tomato	Endosulfan	Organochlorine	0,7-1,75	0,5	2,1
Cucurbits	Fipronil	Phenylpirasol	0,08-0,24	0,05	0,7
Cucurbits, pepper, tomato	Imidacloprid	Neonicotinoid	0,7-1,05	0,6	12,8
Potato, pepper	Lambda-cyhalothrin	Pyrethroid	0,05-0,125	0,03	5,7
Pepper, tomato	Methyl Pyrimiphos	Organophosphate	1,0-2,5	0,8	7,1
Potato, common bean	Thiamethoxan + Lamda-cyhalothrin	Neonicotinoid + Pyrethroid	0,5-0,7	0,5	5,0

Source: Elaborated by the authors

Given the importance of *P. vorax* as a pest species of this crop in Ecuador (Landázuri, Gallegos, & Barriga, 2005) and the other species mentioned, as well as the impact of the insecticides used to control these, it is necessary to conduct studies of the population dynamics and the damages caused in observation lots with no application and interference of pesticides. This will define the real limiting factors of production that allow the evaluation and propose more rational management strategies. There are previous experiences in which alternatives of lower environmental impact have been tested both for *P. vorax* (Landázuri et al., 2005) as well as for *Tecia solanivora* (Povolny) (Lepidoptera: Gelechiidae) (Bosa et al., 2008).

Solanaceae: *Capsicum annuum*: pepper

The major entomological problems reported for pepper cultivation were the aphids *A. gossypii* and *Myzus persicae* Sulzer (Hemiptera: Aphididae), the mite species *Polyphagotarsonemus latus* Banks (Acari: Tarsonemidae) and *Tetranychus urticae* Koch (Acari: Tetranychidae) (Tetranychidae) 0.05), differing significantly from the gall midges *Prodiplosis longifila* (Gagné) (Diptera: Cecidomyiidae). To control these problems, farmers made an average of two weekly sprays of insecticides (table 3). During the field inspections carried out to corroborate the presence of the mentioned species, no infestation or damage by *P. longifila* was observed in any of the pepper crops examined (92 pepper fields), despite being referred to as the second cause of insecticide applications. Valarezo, Cañarte, Navarrete and Arias (2003), reported that in interviews with farmers from different provinces of Ecuador, they listed at least 15 host crops for this species, including pepper. However, the same research indicated that an appreciable percentage of farmers (up to 70 %) mentioned that they did not know other hosts for "this pest" other than tomato.

Prodiplosis longifila is a critical problem in tomato, but not in pepper. According to observations made in pepper fields, the most notorious damages in this crop are those caused by aphids and mites, which prior to evaluation, could easily be controlled with selective applications of neonicotinoids and specific acaricides, respectively. In other words, for pepper, no major phytosanitary limitations were observed and, consequently, the amount of pesticide applications is not justified, including some of high environmental impact and toxicity such as carbofuran, methomyl, and methamidophos (table 4).

Table 6. Slightly toxic insecticides (Class III) and dosage (g or mL of i.a.L^{-1}) used (DU) and recommended (RD) in some crops in the southwestern provinces of Ecuador

Crop	Insecticide	Chemical Group	DU	RD	Use %
Pepper	Acephate + Imidacloprid	Phosphorated + Neonicotinoid	1,13-1,66	1,3	0.7
Common bean, pepper, tomato	Acetamiprid	Neonicotinoid	0,4-0,6	0,13	5,0
Tomato	Ciromazine	Triazine	0,75-2,25	0,13	0,7
Cucurbits, tomato	Chlorphenapir	Pyrrole	0,4-0,6	0,3	1,4
Common bean	Diflubenzuron + Lambda-cyhalothrin	Benzoylurea + Pyrethroid	0,7-0,88	0,62	0,7
Cucurbits, tomato	Malathion	Phosphorated	0,86-1,71	0,4	1,4
Tomato	Thiocyclam	Not classified	0,5-1,0	0,37	0,7

Source: Elaborated by the authors

Solanaceae: *Solanum lycopersicum*: tomato

In this crop, although farmers mentioned whiteflies (Hemiptera: Aleyrodidae) and *Liriomyza* spp. as problems, *P. longifila* was the main reason for insecticide application ($p < 0.05$), initiated a few days after transplantation, and reaching an average of 2.8 applications per week (table 3) (range: 2-4 applications/week). Valarezo et al. (2003) pointed out that for about three decades, *P. longifila* is the species considered as the principal tomato pest of importance in Ecuador. This species was first detected in the country in 1986 in the Arenillas canton (El Oro province), and it was later found in 12 provinces of the coastal zone and inter-Andean valleys, with an altitudinal distribution from the sea level to 1,800 m a.s.l.

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These same researchers mentioned that this insect had restricted the tomato production (about 6,000 ha), so all producers have indiscriminately applied chemical products, and in some areas, farmers left their crops without management due to total loss of profitability. The 2.8 weekly applications detected in this study would represent a total of 45 applications per crop cycle, which is much higher than what Valarezo et al. (2003) reported. These authors referred to a range of 21 to 31 applications made per crop cycle in several provinces of the country and agree that it is an indiscriminate use of pesticides. In summary, the high use of insecticides to control *P. longifila* is probably accentuating phytosanitary, as well as human and environmental health problems (Lindao, Jave, Retuerto, Erazo, & Echeverría, 2017).

Chemical products used

The results showed frequent applications of chemical insecticides made by farmers, which corroborates what was mentioned in previous research carried out throughout the country (Aldás, 2012; Crissman et al., 2002; Valarezo et al., 2003, 2008) and in Latin America (Chirinos & Geraud-Pouey, 2011; Ruiz, Ruiz, Guzmán, & Perez, 2011; Wesseling et al., 2003). None of the farmers stated that they follow the recommendations written in the label of the insecticide containers regarding the waiting period or confidence interval before harvest, necessary to ensure the decomposition of the pesticide.

Of the insecticides used, 31.2, 46.8, 12.9, and 8.4 % are classified in the Toxicity Class I, II, III, and IV, respectively (tables 4-7) (χ^2: 96.89; $p < 0.09$). These results show that the most toxic insecticides, belonging to classes I and II, constituted approximately 80 % of the applications in crops mentioned by farmers. Of the four categories, Class I products referred to by producers, i.e., methamidophos, methomyl, and profenofos, are restricted; moreover, carbofuran was banned in the country (Agrocalidad, 2013). Except for profenofos, these insecticides are proven to be the major causes of acute poisoning in humans in other countries (Fernández et al., 2010).

All farmers (table 8) mentioned mixing two or more insecticides in one spraying session. This is similar to the results obtained by Vargas-González et al. (2016), who detected that 95 % of the farmers surveyed in the melon-producing region of Comarca Lagunera, Mexico, mixed at least two pesticides during one spraying session. When more than one pesticide is used in a spray, the individual toxicity scales lose validity due to the additive effects of the mixtures, which is especially relevant because all the dosages used were significantly higher (W : 4207; $p < 0.05$) to those recommended on the product label (tables 4-7). The additive effects of pesticides occur because these exert a joint action and will be the result of the sum of each of them (Stephens, Maige, Beltran, & González, 2005).

Table 7. Use percentage of insecticides that probably do not cause any risks (Class IV) and dosage used (DU) and recommended (RD), expressed in grams or milliliters per liter

Crop	Insecticide	Chemical Group	DU	RD	Use %
Common bean	Buprofezin	Thiadazine	0,67-1,34	0,25	0,7
Pepper	Dicofol	Organochlorine	0,46-0,93	0,3	5,7
Pepper	Dicofol + Tetradifon	Organochlorine	0,7-1,1	0,65	0,7
Pepper	Tetradifon	Organochlorine	0,15-0,3	0,1	0,7
Cucurbits, tomato	Thiamethoxam	Neonicotenoid	0,5-0,75	0,5	2,1

Source: Elaborated by the authors

Table 8. Percentage of farmers who mix products and source of pest management consultancy

		Pest management consultancy		
Crop	**Mixture of products (%)**	**Own experience**	**Particular**	**Agrochemical sellers**
Common bean	100	30.8	4.6	64.6
Cucurbitaceae	100	31.8	13.6	54.5
Tomato	100	38.6	19.3	42.1
Pepper	100	30.4	6.8	62.7
Tomato	100	21.7	9.6	68.7

Source: Elaborated by the authors

It was common to observe empty chemical insecticide containers scattered in the crop fields (figure 3). As for the preparations and spraying sessions, these were carried out by agricultural operators without body protection, which could compromise their health, especially as most were relatively young (Lindao et al., 2017). Furthermore, the manipulation of fruits covered with pesticide residues during the collection, selection, and cleaning using their bare hands, and the accommodation of these in the transport baskets, are operations that are usually carried out by women and children. Studies in Ecuador detected the presence of chlorinated pesticide residues in the final potato, pepper, and tomato products, but with quantities that did not exceed the maximum permitted limits (Ministerio de Ambiente, 2004). Other research carried out on the basic family basket in tomato samples collected in four provinces of the country, showed that methamidophos pesticide residues had values eight times above the Maximum Residue Limit (MRL) (Crissman et al., 2002).

Figure 3. Pesticide containers dispersed in crop fields in Ecuador. a. Arenillas, province of Gold; b. Pedro Carbo, Guayas province; C. Pallatanga, province of Chimborazo; d. El Morro, province of Santa Elena.

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For the control of agricultural pests, an average of 58 % (range: 42-69 %) of the interviewees reported that representatives of pesticide trading houses advise them on this topic (table 8). Valarezo et al. (2003) reported that chemical recommendations to farmers come from sellers of agricultural inputs, and, on other occasions, they rely on their own experience.

The results show the high use of chemical insecticides in the locations and crops studied. These are widely used in agriculture because they are effective, have a rapid effect and are flexible in adapting to many agronomic and ecological conditions. Besides, it is the only pest management tool that can be used when damage levels are excessive and are an effective alternative. For these to be used harmoniously within the context of pest management, it is necessary to replace the application schedules with the treatments that are required and recognize that 100 % insect control is not necessary to prevent economic losses (Luckmann & Metcalf, 1975).

Additionally, the efficiency of sprays should be improved and, where the situation allows, localized and targeted applications should be performed. It is also vital to reduce the dosages to the minimum necessary and respect the waiting periods or application times established before harvest. These results demand studies of pesticide residuals in the final agricultural products, as well as the impact on the health of operators and consumers, and the effects on the environment due to the use of chemical pesticides.

Given this serious situation of high application of chemical insecticides, it is essential to propose alternatives, for which knowledge about the ecological dynamics of agroecosystems is essential, especially with regard to arthropod fauna and their trophic interactions, to define the real problems that need to be managed and how to do it, without generating new problems (Chirinos & Geraud-Pouey, 2011). The first alternative to be considered within an integrated pest management program is the action of the natural biological controllers that, in some cases, such as the species of the *Liriomyza* genus, is generally sufficient to maintain the population of this phytophagous insect controlled in different crops (Chirinos et al., 2014; 2017; Tran et al., 2006).

When natural biological control is not enough, other alternatives must be considered before chemical control is used. The biological control applied has been successful in management programs of some agricultural pests in several countries of the Neotropical region (Colmenarez, Corniani, Jahnke, Sampaio, & Vásquez, 2018). Microbial insecticides are also part of low environmental impact management strategies, due to their biological selectivity, whose active ingredients based on fungi, bacteria, and baculovirus, among others, have demonstrated effectiveness for the control of different important pest species in various crops (Ayala & Henderson, 2017; Landaruzi et al., 2005; Portela-Dussán, Chaparro-Giraldo, & López-Pazos, 2013). Likewise, botanical insecticides, as well as the use of pheromones, have shown their effectiveness in the control of agricultural pests (Bosa et al., 2008; Campos et al., 2018).

Conclusions

Integrated pest management is a system that based on the knowledge of the agroecosystem, uses in the most compatible way possible, all the necessary and available alternatives to keep pest populations at levels that do not cause significant damage (Smith & Reynolds, 1965). Therefore, this does not represent an alternative, but a continuous effort to use the correct approach and management of pest problems, that is, to undertake the solution of pest problems in a rational way from ecological, economic and social points of view (Luckmann & Metcalf, 1975; Vivas-Carmona, 2017).

Disclaimers

The authors state that there are no conflicts of interest.

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